Method for the production of reflective optical elements, reflective optical elements, EUV lithography apparatuses and methods for the operation of optical elements and EUV lithography apparatuses

Technical field of the invention

The invention relates to a method for the production of multilayer systems with cover layer system, in particular reflective optical elements for the extreme ultraviolet to soft X-ray wavelength range, to a corresponding reflective optical element for the extreme ultraviolet to soft X-ray wavelength range, and also an EUV lithography appliance comprising at least one such reflective optical element.

Moreover, the invention relates to a method for the production of a reflective optical element for the extreme ultraviolet to soft X-ray wavelength range comprising a cover layer system having a constant thickness, to a reflective optical element for the extreme ultraviolet to soft X-ray wavelength range comprising a cover layer system having a constant thickness, and also to an EUV lithography appliance comprising at least one such reflective optical element.

The invention also relates to a reflective optical element composed of a multilayer system with cover layer system, which has at least one layer composed of a transition metal, wherein the multilayer system is optimized for an operating wavelength in the extreme ultraviolet to soft X-ray wavelength range, to a lithography appliance comprising at least one such reflective optical element, and also to methods for the operation of reflective optical elements.

Furthermore, the invention relates to an EUV lithography apparatus, and to a method for the operation of such an EUV lithography apparatus.

Background of the invention

Optical reflective elements for the soft X-ray to EUV wavelength range (e.g. wavelengths of between 5 nm and 20 nm), such as photomasks or multilayer mirrors, for example, are required in particular for use in the EUV lithography of semiconductor components. Typical EUV lithography appliances have eight or more reflective optical elements. In order nevertheless to achieve a sufficient total intensity of the operating radiation, the mirrors have to have the highest possible reflectivities because the total intensity is proportional to the product of the reflectivities of the individual mirrors. The reflective optical elements should maintain this high reflectivity as far as possible during their entire lifetime. Furthermore, the homogeneity of the reflectivity over the surface of the reflective optical elements has to be maintained over the entire lifetime. The reflectivity and the lifetime of these reflective optical elements are adversely affected particularly by the contamination of the surface under irradiation at the operating wavelength in the form of the deposition of carbon and by oxidation of the surface.

The reflective optical elements become contaminated by residual gases from the vacuum atmosphere during operation. In this case, molecules of the residual gas are firstly adsorbed on the surfaces of the reflective optical elements and are subsequently dissociated by the high-energy photon radiation by means of emission of secondary electrons and in part also photoelectrons. In the case where hydrocarbons are present in the residual gas atmosphere, this gives rise to a carbon layer that decreases the reflectivity of a reflective optical element by approximately 1% per nm thickness. Given a hydrocarbon partial

pressure of approximately 10^{-9} mbar a layer having a thickness of 1 nm is already attained after approximately 20 hours. Since, by way of example, EUV lithography appliances no longer permit the required throughput in the case of a loss of reflectivity of 1% per reflective optical element, this contamination layer has to be removed by a cleaning process, which can last up to five hours. Moreover, such a cleaning process is associated with the risk of the surface of the reflective optical element being damaged, for example roughened or oxidized, and, therefore, the initial reflectivity not being attainable again.

Oxygen-containing residual gas molecules can contribute to the oxidation of the surfaces. In this case, the unprotected surface of a reflective optical element could be destroyed within as little as a few hours.

Conventional multilayer systems are produced by materials that have different refractive indices and/or different absorption coefficients being deposited one above another in a plurality of layers on a substrate. They are used as mirrors in particular in the extreme ultraviolet wavelength range. Other application possibilities for multilayer systems include, in the visible wavelength range, for example, antireflection coatings of optical elements.

The reflection of electromagnetic radiation at a multilayer system is based on interference between the radiation reflected at the many interface layers of the multilayer system, and it is described by Bragg's law. This reflection is therefore of a dispersive nature. The reflectivity of the interface layer between two such layers for electromagnetic radiation in a wavelength range of <50 nm is a few per mille for angles greater than the critical angle. Reflectivities of up to the order of magnitude of 70% can be obtained for such angles with multilayer systems. Multilayer systems are therefore used to achieve high

reflectivities at large angles relative to the layer surface, and can also be used as dispersive elements.

A multilayer system for the reflection of short wavelengths consists of progressive periods of in each case two or more layers of materials having different refractive indices and thicknesses, for example of the order of magnitude of the wavelength of the reflected radiation. The total reflectivity of a multilayer system is determined by the order of magnitude of the reflection per interface, that is to say the difference between the refractive indices and, on the other hand, the absorption coefficients.

The thicknesses of the individual layers are usually constant for each material over the multilayer thickness. Depending on the requirement made of the mirror with regard to the reflection profile, however, all possible other multilayer systems are also conceivable.

Predominantly molybdenum/silicon or molybdenum/beryllium systems are taken as a basis in the EUV range.
For protection against external influences such as contamination, for example, a cover layer system can be provided on the surface of the reflective optical element. The contamination or degradation of the surface of the reflective optical elements can be positively influenced by the choice of selected cover layer materials. What can be achieved by varying the thickness of the one or more cover layers is that, despite the cover layer system, the reflectivity of the reflective optical element does not decrease to an excessively great extent.

Optical elements composed of a substrate and a multilayer system which is optimized for high reflectivities at a specific wavelength, e.g. photomasks or mirrors for the extreme ultraviolet wavelength range

(EUV) are required in particular for use in the EUV lithography of semiconductor components.

It has already also been proposed to minimize the general degradation and specifically the contamination by carbon-containing substances, or to make their influence manageable, not just by means of the material selection but by means of the geometry of the cover layer system. A targeted choice of the thickness distribution of the cover layer system makes it possible to control how much contamination occurs at what locations of the surface. As a result, the contamination becomes calculable and can be taken into account during the operation or in the conception of reflective optical elements, optical systems and EUV lithography apparatuses.

In the past it has been proposed to determine the structure of the layers of a multilayer system and in particular the roughness at the layer interfaces by measuring both the reflectivity and the photoelectron current simultaneously on a sample. Radiation in the X-ray range is used for this purpose. This proposal is based on the assumption that the spectrum of the current normalized to the radiation dose is proportional to the spectrum of the standing X-ray wave that forms in the case of resonance, and the shape of the spectrum is dependent on layer structure and interface roughness. In a corresponding measuring apparatus, monochromatized light in the range around 100 eV is made available with the aid of a monochromator. Said light is directed onto a sample having a degree of freedom of rotation for changing the angle of incidence. Photodiodes are typically used for measuring the reflectivity. A network situated in the beam path between monochromator and sample is used for measuring the radiation dose. For measuring the current flowing in the sample, the multilayer system is connected to an ammeter via a cable.

The simultaneous measurement of reflectivity and photoelectron current for characterizing multilayer systems had already been proposed earlier, in principle. This assumed that the phase shift between reflectivity and photoelectron current is generally $\pi/2$.

In order to deposit extremely uniform thin layers on planar or curved substrates, the procedure can be such that firstly the particle flow of the coating source is determined with the aid of a test substrate. Layer thickness profiles can be calculated therefrom, different relative movements between substrate and source also being taken into account. Proceeding from this it is possible to determine how the desired thickness distribution can be obtained. In order to optimize the coating parameters, actually obtained layer thicknesses are measured by the coating being removed or etched away in places and the height difference with respect to the residual coating being measured with the aid of profilometers. Vertical resolutions to a minimum of 3 nm can be achieved using commercially available profilometers.

The iterative optimization of design and production process for multilayer systems for reflective optical elements composed of two materials applied alternately is already known. Firstly, a first layer of each of the two materials is applied. The thickness distribution thereof is determined and the coating parameters for the desired layer thicknesses of the remaining layers are thereupon defined. The characterization of the layer thicknesses, of the period length and of the roughness at the interfaces is determined with the aid of reflectivity measurement and the comparison thereof with modeled data.

In a further development of condenser systems for EUV lithography systems composed of collector unit and grating, wherein the grating can be coated with a multilayer system, a collector unit for wavelengths of less than 193 nm right into the EUV wavelength range is known, the

main constituent of which is a mirror shell for generating a uniform and telecentric image of the radiation source, which has a grating structure on its surface. Said grating structure diffracts different wavelengths in different directions. The desired diffraction order or wavelength can be selected with the aid of a slit diaphragm. Moreover, the slit diaphragm affords protection against particles which, if appropriate, can originate from the radiation source.

Control loops for avoiding contamination on surfaces of reflective optical elements on the basis of multilayer systems during their irradiation at operating wavelengths in the EUV range in an evacuated, closed system having a residual gas atmosphere are already known. In this case, the photoelectron current generated by emission of photoelectrons from the irradiated surface of the multilayer system is measured. The regulation of the gas composition during the irradiation is carried out in a manner dependent on the measured photoelectron current by a procedure in which, in the case of one threshold value being reached or exceeded, at least one gas is supplied to the closed system and the supply of said gas is at least reduced subsequently before or when another threshold value is reached.

In order to reduce the contamination of optical elements having a multilayer system, it has been assumed hitherto that the layer material and/or the layer thickness of at least one layer of the multilayer system should be chosen in such a way that the standing electromagnetic wave that forms upon reflection of the incident operating wavelength has a node of the electric field strength in the region of the free interface of the multilayer system. This minimizes the emission of photoelectrons from the surface which would otherwise initiate reactions e.g. with the residual gas, which could lead to intensified contamination.

In the past it has been pointed out that the contamination of surfaces of reflective optical elements for the soft X-ray and extreme ultraviolet wavelength range can be avoided particularly efficiently if firstly the reflective optical elements are provided with a cover layer comprising one or a plurality of transition metals, and secondly the irradiation at operating wavelength takes place in an evacuatable, closed system having a residual gas atmosphere, wherein a reducing gas or gas mixture and an oxidizing gas or gas mixture should simultaneously be present in the residual gas atmosphere. The partial pressures can be established such that oxidizing and reducing processes at the surface of the reflective optical element balance one another, which has the effect that no appreciable contamination takes place. A residual gas atmosphere composed of hydrocarbon, water and oxygen is particularly preferred.

Lithography appliances for the X-ray range which have diverse detectors in order to monitor the radiation intensity during the irradiation of the mask and the wafer are already known. By that means, deformations of the mirrors which are caused by the thermal load are detected, and the contamination state of the mirror surfaces is monitored. Particularly for detecting the deformations and the contamination state, recourse is had to the photoelectric effect. The deformations determined are compensated for during the exposure operation mode. If it is ascertained that a mirror is contaminated, then a signal that said mirror has to be replaced or serviced is effected.

Consideration has already been given also to cleaning EUV lithography apparatuses or the parts thereof in situ by using the EUV radiation. By way of example, in addition to the actual operating reticles, it is also possible to have available cleaning reticles optimized toward directing the cleaning beam at the locations to be cleaned.

Attempts have been made to avoid contamination by oxidation, by means of hydrocarbons, specifically alcohol, being admixed with the residual gas atmosphere. In this case, although a self-terminating carbon layer is expected to deposit on the surface of a reflective optical element as a result, long-time experiments > 100 hours have proved that the carbon layer continues to grow slowly.

It is known that the carbon contamination can be removed by the addition of a cleaning gas. Oxygen, hydrogen and water are proposed as cleaning gas. What is problematic, however, is that not only is the carbon contamination layer removed, but oxidation of the surface lying under the contamination can also be caused, under certain circumstances.

It has been proposed to achieve, by addition of, in particular, ethanol and water in a ratio of 2:1 into the residual gas atmosphere, simultaneous removal of carbon deposits from the surface of a multilayer system composed of Mo/Si without a cover layer system, that is to say terminating with a silicon layer.

A protective layer that significantly reduces the susceptibility to oxidation has been described. This lengthens the lifetime of a reflective optical element. Lifetimes of several years have to be achieved for the economic use of the reflective optical elements in, for example, an EUV lithography appliance.

A further approach for avoiding losses of reflectivity as a result of contamination consists in providing a photocatalytic protective layer, e.g. an oxide of a transition metal, such that free oxygen radicals arise upon irradiation with EUV radiation, which react with carbon deposits to form volatile compounds. If appropriate, oxygen, water and/or peroxide are fed in.

Summary of the invention

One object of the invention is to specify a production method for multilayer systems with cover layer system. Moreover, it is an object of the invention to specify a reflective optical element produced therewith, and an EUV lithography appliance in which such an element is used.

Furthermore, it is an object of the present invention to specify a method for the production of a reflective optical element comprising a cover layer system having a constant thickness, and also a corresponding reflective optical element and an EUV lithography appliance operating therewith.

A further object of the present invention consists in specifying a reflected optical element optimized against contamination for the extreme ultraviolet to soft X-ray wavelength range, and also an EUV lithography appliance based thereon, and methods for the operation of such a reflective optical element.

Furthermore, the object is to specify an EUV lithography apparatus having a lifetime that is as long as possible, and also a method for the operation of such an EUV lithography apparatus.

The invention consists in a method for the production of multilayer systems with cover layer system, in particular reflective optical elements for the extreme ultraviolet to soft X-ray wavelength range, comprising the following steps:

1. designing a coating design for the multilayer system with cover layer system;

2. coating a substrate with the multilayer system with cover layer system;

3. spatially resolved measurement of the coated substrate with regard to reflectivity and photoelectron current at at least one surface point;

4. comparing the measurement data with data modeled for different thicknesses of the layers of the cover layer system and/or of the layers of the multilayer system for determining the thickness distribution achieved by the coating;

5. if appropriate adapting the coating parameters and repeating steps 2 to 5 until the coated thickness distribution corresponds to the design;

and also a reflective optical element produced in this way for the extreme ultraviolet to soft X-ray wavelength range, and an EUV lithography appliance comprising at least one such reflective optical element.

In one specific embodiment, the invention consists in a method for the production of a reflective optical element for the extreme ultraviolet to soft X-ray wavelength range comprising a cover layer system having a constant thickness, comprising the following steps:

1. designing a coating design for the multilayer system with cover layer system;

2. coating a substrate with the multilayer system with cover layer system;

3. measurement of the coated substrate with regard to reflectivity and photoelectron current at at least one surface point;

4. comparing the measurement data with data modeled for different thicknesses of the layers of the cover layer system for determining the thickness distribution achieved by the coating;

5. if appropriate adapting the coating parameters and repeating steps 2 to 5 until the coated thickness distribution corresponds to the design;

and also a reflective optical element produced in this way for the extreme ultraviolet to soft X-ray wavelength range comprising a cover layer system having a constant thickness, and an EUV lithography appliance comprising at least one reflective optical element of this type.

Furthermore, the invention consists in a reflective optical element for the extreme ultraviolet to soft X-ray wavelength range composed of a multilayer system with cover layer system comprising at least one layer composed of a transition metal or of a transition-metal-containing alloy, compound or mixture and optimized for an operating wavelength in the extreme ultraviolet to soft X-ray wavelength range, which is distinguished by the fact that at least one layer or cover layer thickness is chosen in such a way that, upon irradiation with the operating wavelength, a standing electromagnetic wave forms in such a way that it has an intensity maximum in the region of the free interface of the reflective optical element. In further embodiments, this invention consists in an EUV lithography appliance comprising at least one reflective optical element of this type in an evacuatable housing and at least two feed lines which open in the region of the reflective optical element and serve for feeding an oxidizing gas or gas mixture and a

reducing gas or gas mixture, and also a method for the operation of a reflective optical element of this type in a closed system comprising a residual gas atmosphere composed of a hydrocarbon, water and oxygen, in which, at the beginning of irradiation with the operating wavelength, the hydrocarbon partial pressure is increased in such a way that carbon deposits on and/or in the topmost layer, such that the intensity maximum of the standing electromagnetic wave that forms is situated at the free interface.

In further modifications, the invention consists in a method for the operation of the abovementioned reflective optical element in a closed system comprising a residual gas atmosphere having a reducing gas fraction and an oxidizing gas fraction, in which the partial pressures of the gas fractions are set in such a way that oxidizing and reducing reactions are in equilibrium at the topmost cover layer.

Furthermore, the invention consists in a method for the operation of a reflective optical element for the extreme ultraviolet to soft X-ray wavelength range composed of a multilayer system comprising a topmost cover layer composed of carbon and/or an oxide in a closed system comprising a residual gas atmosphere having a reducing gas fraction and an oxidizing gas fraction, in which the partial pressures of the gas fractions are set in such a way that oxidizing and reducing reactions are in equilibrium at the topmost cover layer, and a lithography appliance comprising at least one reflective optical element for the extreme ultraviolet to soft X-ray wavelength range composed of a multilayer system comprising a topmost cover layer composed of carbon and/or an oxide, in which at least one layer or cover layer thickness is chosen in such a way that, upon irradiation with the operating wavelength, a standing electromagnetic wave forms in such a way that it has an intensity minimum in the region of the free interface of the optical element, comprising an evacuatable housing, in which the

reflective optical element is arranged, and at least two feed lines which open in the region of the reflective optical element and serve for feeding an oxidizing gas or gas mixture and a reducing gas or gas mixture.

A final aspect of the invention consists in an EUV lithography apparatus comprising at least one photoelectron detector, if appropriate comprising means for setting a residual gas atmosphere within the EUV lithography appliance and comprising at least one tunable monochromator in the beam path, such that the incident wavelength can be altered, in particular can be changed between the operating wavelength and at least one used wavelength, and also a method for the operation of such an EUV lithography apparatus, in which, at predetermined times, a changeover is made from radiation operation to the detection mode by virtue of the fact that

1. in a targeted manner, the location to be examined is irradiated and, with tuning of the monochromator, the photoelectron current and, if appropriate, the reflectivity are measured in a manner dependent on the wavelength;

2. the contamination state is determined from the determination of the spectral profile of photoelectron current in the range of maximum reflectivity and/or the comparison of the measured photoelectron current data with data modeled for different contamination states.

Advantageous configurations are found in the dependent claims.

Brief description of the figures

The invention will be explained in greater detail with reference to the following figures. In this respect,

Figure 1a	shows a production method for reflective optical elements;
Figure 1b	shows a modification of the method illustrated in figure 1a;
Figures 2a,b,c, d	show measurements of the reflectivity and of the photoelectron current in the case of different carbon thicknesses and in the case of oxidation;
Figures 3a-n	show calculated reflectivity and photoelectron current curves for different carbon thicknesses and also the intensity profile of a corresponding standing electromagnetic wave that forms in the case of resonance;
Figure 4	shows a basic schematic diagram of a reflective optical element;
Figure 5	shows an operating method for a reflective optical element;
Figures 6a,b	show measurement curves of the photoelectron current and of the reflectivity for different operating states;
Figure 7	shows an EUV lithography apparatus;
Figure 8	shows an operating method for the EUV lithography apparatus illustrated in figure 7.

Detailed description of the invention

The previously known production methods for multilayer systems with cover layer system have the disadvantage that the determination of the thickness of the individual layers can be performed only very inaccurately. By means of reflectivity measurements, in particular, it is only possible to determine average layer thicknesses over the depth of the entire multilayer system. However, this information is usually sufficient for the optimization of the coating process of multilayer systems without cover layer system for optimum reflectivity. The problem is more serious in the production of multilayer systems with cover layer systems. The cover layer system interrupts the periodicity, such that reliable statements about the layer thicknesses cannot be made by means of pure reflectivity measurements. However, complying with the desired layer system as exactly as possible is very important precisely in the case of the cover layer systems with regard to the lifetime properties, in particular the resistance to contamination in conjunction with the highest possible reflectivity.

The measurement principle presented here is based on the fact that changes in the thickness of the cover layer system, which can consist of one or a plurality of layers, is manifested in large fluctuations of the photoelectron current at this coating, while the change in the reflectivity turns out only to be weak.

It is assumed that the physical basis is that the photoelectron current in the range of resonance is to a first approximation proportional to the intensity of the standing electromagnetic wave in the region of the free interface that forms at the multilayer system in the case of resonance. The position of the maximum of the reflectivity is primarily determined by the design of the multilayer system per se, while the thickness of the cover layer system or of the individual layers thereof determines where

the free interface with respect to the vacuum of the overall system is situated. Depending on the intensity assumed by the standing wave exactly at said free interface, more or fewer photoelectrons emerge. The intensities of the standing wave for any desired designs can be calculated by means of customary simulation programs. By comparing the modeled data with the measured data, it is possible to accurately determine the thicknesses of the layers of the cover layer system right into the subangstrom range. With regard to the optimization of the coating parameters, the spatially resolved measurement of the entire surface is of great importance in this case.

When starting with coating designs and coating processes that have already been optimized in the past for multilayer systems, it suffices, for the case of the production of these known multilayer systems with additional cover layer systems, to concentrate on the determination of the thickness distribution of the cover layer system.

Depending on the application of the multilayer system with cover layer system or depending on the conditions of use of the multilayer system, it can be expedient to provide the thickness distribution of the cover layer system over the entire surface either as constant or else as variable, e.g. in order to compensate for a high thermal load, high local risk of contamination and the like.

The production method is preferably extended to the effect that the coating design is also optimized with the aid of said production method by a procedure in which multilayer systems with cover layer system obtained in a first pass are tested in simulation calculations with respect to optical systems in which the multilayer system obtained is used and the simulation results are compared with specifications established beforehand, e.g. with regard to the lifetime or imaging characteristics. What may be of interest in this case is e.g. the change in contamination

with the radiation load or the intensity distribution in the beam spectrally and geometrically shaped by the multilayer system or optical system. Depending on the result, either the coating design is modified and a new optimization loop of the coating process is started or it is ascertained that the multilayer system with cover layer system fulfills the specifications.

The method can furthermore be optimized by the multilayer system being tested in the radiation operation mode and the test results being compared with specifications established beforehand. In this case, the multilayer system can be measured as an individual optical element or else as a constituent of an optical system. This last is recommended, in particular, if simulation calculations with respect to this optical system have been effected beforehand. Once again, depending on the result, either the coating design - if appropriate, also the design of the optical system - and a new optimization loop of the coating process is started or it is established that the multilayer system with cover layer system fulfills the specifications.

All important process parameters for production would thus be determined, and so e.g. reflective optical elements for the extreme ultraviolet to soft X-ray wavelength range can also be subjected to series production.

Particularly good results can be achieved if use is made of an EUV source with the highest possible brilliance, e.g. a synchrotron radiation source or laser- or discharge-induced plasma sources optimized for small beam spot sizes, and care is taken to ensure that the surface of the entire system is completely scanned. For the coating process itself it is possible to have recourse to all coating methods already known, such as e.g. electron beam evaporation, sputtering, in particular magnetron sputtering, etc.

One particular embodiment involves producing a reflective optical element for the extreme ultraviolet to soft X-ray wavelength range with a cover layer system having a constant thickness over the entire surface according to the principle just illustrated. As already explained, it is possible either to be restricted to the optimization of the coating parameters or else to optimize the coating design - if appropriate including the design of an optical system having the reflective optical element - itself. In this case, one important optimization goal is to maximize the lifetime of the reflective optical element in conjunction with a reflectivity that is still as high as possible at the operating wavelength.

Advantageously, the production of reflective optical elements for the extreme ultraviolet wavelength range proceeds from a multilayer system that is constructed alternately from molybdenum and silicon layers. Generally, this multilayer system is constructed in a periodic fashion. Depending on the specification for the reflective optical element, however, it may also be necessary to vary the periodicity or else the individual layer thicknesses over the entire multilayer system. Moreover, there is no restriction to using two alternating materials. By way of example, interlayers preventing diffusion of the individual layers are often also included in a design. This leads to a reflectivity which is high stably over a longer time.

The cover layer system is not constructed in a periodic fashion, but rather optimized to protecting the underlying multilayer system against external influences as efficiently as possible. In this case, the main problem is the contamination, which can be manifested e.g. in carbon deposits or else oxidation of the surface.

Particularly preferably, cover layer systems consist of e.g. a layer of silicon, a layer of molybdenum and a topmost layer of silicon. When the

reflective optical element is started up or already when it is exposed to the normal ambient atmosphere, the topmost silicon layer, in accordance with the surrounding atmosphere, is at least partly converted into inert silicon dioxide and/or coated with carbon. The layer thicknesses of the silicon-molybdenum-silicon cover layer system are chosen such that a highest possible reflectivity is still afforded after the growth of a silicon oxide layer and/or carbon layer. Further preferred cover layer systems are based on transition metals. The following are particularly preferred: gold, platinum, rhodium, ruthenium, palladium, silver, rhenium, osmium, and/or iridium, in particular on molybdenum-silicon multilayer systems.

The use of reflective optical elements produced in this way in EUV lithography appliances leads to EUV lithography appliances having a long lifetime. The reflective optical element according to the invention can be incorporated at any desired locations in the EUV lithography appliance, e.g. in the illumination system or in the projection system. This applies to all reflective optical elements described here.

Hitherto, the cover layer system for multilayer systems for reflective optical elements for EUV lithography has generally been optimized with regard to maximum reflectivity. In this case, a distinction is made between two main types of cover layer system designs. In the case of the so-called "Capped Coatings“, the cover layer system consists e.g. of a molybdenum layer and an oxidation-resistant layer composed of preferably gold, platinum, rhodium, ruthenium, palladium, silver, rhenium, osmium, and/or iridium, as terminating layer. In the case of the so-called "Uncapped Coatings“ the cover layer system generally consists of a silicon layer having a thickness of approximately 2 to 3 nm and a silicon oxide layer having a thickness of approximately 1 to 2 nm as terminating layer, wherein said silicon dioxide layer is generally not applied in a targeted manner, but rather forms automatically after the

coating process e.g. as a result of removal into the atmosphere or start-up as a result of oxidation of the silicon layer.

When attempting to optimize the multilayer systems with cover layer system also with regard to low contamination, two approaches have been pursued hitherto. In the case of the so-called "Uncapped Coatings“, in particular, this involves attempting to choose the individual layer thicknesses such that the minimum of the intensity of the standing electromagnetic wave that forms at operating wavelength is situated directly at the free interface. It is assumed here that in this way photoelectrons which would otherwise cause a higher reaction rate between radiation, residual gas atmosphere, charged particles and surface occur only minimally. A further approach for reducing or avoiding contamination in the case of "Capped Coatings“ consists in setting the ratios of reducing and oxidizing gases, e.g. hydrocarbons, oxygen and water in the residual gas atmosphere and also the material at the free interface, preferably transition metals, in such a way that an equilibrium state that does not lead to any adverse influences on the stability and reflectivity of the coatings is established under irradiation conditions. Said equilibrium state is achieved by virtue of the fact that, under irradiation conditions in said residual gas atmosphere, some additional oxygen is incorporated into the topmost transition metal layer and some additional carbon is deposited thereon. With a loss of reflection of at most 1%, within a few minutes an equilibrium state is thus established which varies only within these limits over the entire lifetime.

In the case of the latter multilayer systems whose cover layer system has one transition metal or a plurality thereof, it has now emerged that the equilibrium state just mentioned is stablest if the intensity maximum of the standing electromagnetic wave that forms is situated in the region of the free interface. Presumably, the contamination suppression

process presented is dependent not only on a suitable residual gas combination of reducing and oxidizing gas fractions, e.g. hydrocarbon, oxygen and water, on the one hand, and a metallic, presumably catalytic active surface of the cover layer system, on the other hand, but also on the presence of reaction-promoting free electrons. The positioning of the maximum of the standing wave in the vicinity of the free interface now has the effect that a maximum number of reaction-promoting electrons are always provided.

In one preferred embodiment, the cover layer design is chosen such that, before start-up, the free interface is situated in a manner drawn back somewhat relative to the intensity maximum. Upon start-up in a residual gas atmosphere comprising hydrocarbon or when the reflective optical element is stored under atmospheric conditions over a time period of a plurality of weeks, carbon deposits on the surface. By setting an equilibrium between processes of the oxidation and removal of the surface and also reduction and addition of carbon on the surface, an equilibrium is formed, which has the effect that the carbon layer has a thickness precisely such that the intensity maximum of the standing electromagnetic wave is situated exactly at the free interface. The setting of this equilibrium can be accelerated by the readjustment of the partial pressures. The contamination state is monitored by in-situ measurements of the photoelectron current and, if appropriate, the reflectivity at this reflective optical element. Instead of simultaneously measuring the reflectivity, it is also possible to have recourse to reflectivity curves calculated with knowledge of the design of the multilayer system. By virtue of the fact that a carbon layer is present at all events, the risk of a degradation of the surface as a result of undesired oxidation reactions is also reduced.

A further advantage of the initial carbon deposition is that the carbon is added not only on the topmost layer but also in the surface region of the

matrix of the topmost layer. This firstly prevents further the penetration of oxygen and hence the further oxidation of the surface. At the same time, however, this added carbon is itself largely protected against removal, e.g. by oxidation, on account of the fixed linking into the matrix. Carbon that is nevertheless removed is continuously compensated by the high proportion of hydrocarbons in the residual gas. Carbon projecting as it were from the matrix of the surface, by contrast, is continuously removed on account of the high proportion of oxidants, e.g. water and oxygen, in the residual gas.

The overall consequence is that although contamination processes in the form of carbon deposits always take place, this scarcely leads to an impairment of the reflectivity since the addition of carbon to the surface matrix of a cover layer system on the basis of transition metals is effected in the manner of a passivation only with a subangstrom thickness. Consequently, neither an increase in the mass density nor an appreciable displacement of the free interface occurs. In the case of oxidation, a displacement of the free interface likewise does not occur, but oxygen is incorporated, in particular, into deeper regions of the surface matrix, which leads to an increased mass density and hence increased absorption. The additional incorporation of some oxygen into the topmost incorporation of some oxygen into the topmost transition metal layer has the advantage that the further incorporation of oxygen can thereby be prevented.

In the case, too, of reflective optical elements comprising topmost cover layers composed of an oxide and/or carbon, it has been found to be advantageous to operate in a residual gas atmosphere in which reducing and oxidizing reactions at the surface balance one another, specifically deposition of carbon and formation of an oxidation layer e.g. as a result of addition of oxygen, hydrogen and at least one hydrocarbon, such that no appreciable losses in reflectivity occur even

over long operating times. Preferably, however, the layer design is optimized to the effect that the standing wave that forms in the case of resonance forms an intensity minimum at the free interface. As a result, as few free electrons as possible are provided at the surface, which overall has a damping effect on all reactions proceeding at the surface. This ensures that no appreciable contamination forms.

The lifetime of EUV optical units can be attained not only by optimizing e.g. the coating design as described above, but also by improving the entire EUV lithography apparatuses with regard to in-situ monitoring, cleaning and also repair. The invention proposes that the EUV lithography apparatus has at least one photoelectron detector in addition to the customary elements such as e.g. optical elements. This can also involve an ammeter connected directly to the reflective optical element via a cable. A photon detector for simultaneously measuring the reflectivity can additionally be provided if there is no intention to have recourse to reflectivity curves calculated with knowledge of the multilayer system design. Moreover, means for setting a residual gas atmosphere within the EUV lithography appliance, and at least one tunable monochromator should be present. By way of example, a rotatably mounted grating of a condenser system on an EUV lithography appliance can serve as a tunable monochromator. By means of the tuning of the monochromator, e.g. by means of the rotation of the grating, the angle of incidence is altered and hence so is the wavelength of the radiation in the EUV lithography appliance. It is useful if it is not only possible to change coarsely between two angles of incidence but also possible to pass through an angular range in the smallest possible steps.

With the aid of these constituents, at predetermined times, which can also be stored in a control computer in the course of full automation of the EUV lithography apparatus, a changeover can be made to the so-

called detection mode. In order to avoid adverse effects on the location to be examined within the lithography apparatus, e.g. at mirrors to be examined, the residual gas composition can be suitably optimized at least at the location to be examined. If a low-contamination residual gas mixture composed of e.g. hydrocarbon, water and oxygen is used, in this case care should be taken to ensure that the ratios of the constituents to one another are maintained in such a way that the low-contamination equilibrium is maintained. The location to be examined is irradiated in a targeted manner and, with tuning of the monochromator, the photoelectron current and, if appropriate, the reflectivity are measured in a manner dependent on the wavelength at the relevant location. The contamination state can then be determined (detection mode) from the determination of the spectral profile of photoelectron current and the reflectivity and/or the comparison of the measured photoelectron current data with data modeled for different contamination states. By means of this in-situ examination, the functional state of the EUV lithography apparatus can be determined with extremely low outlay.

The method can be extended to the effect that in the case of first controlled variables being exceeded, e.g. specific profiles of the photoelectron current curve which indicate an increased contamination, the residual gas atmosphere is modified to the effect that the contamination is reduced (cleaning mode). In the case of second controlled variables being exceeded, e.g. likewise specific profiles of the photoelectron current curve which indicate damage at the surface, not only is the composition of the residual gas atmosphere modified, but the incident beam is also modified with regard to its cross section and its position, such that material can be locally added and/or removed in a defined manner (repair mode). The detection and cleaning modes also preferably operate in a spatially resolved manner.

It can be expedient, in the detection mode, in the cleaning mode and/or in the repair mode, to alter partial pressures in the lithography appliance at least at the illuminated location in order to avoid undesired effects such as e.g. an excessively high degree of oxidation.

It can furthermore be expedient, in the detection mode, in the cleaning mode and/or in the repair mode, to change over from the normal operating wavelength to a used wavelength that differs therefrom with the aid of the monochromator. The background here is that different wavelengths, on account of different phase angles of the standing wave that forms upon reflection, cause different photocurrents and can be used in a targeted manner for detection, repair and/or cleaning purposes by using the entire available wavelength spectrum within the EUV lithography apparatus.

In this case, by way of example, a cleaning reticle or suitable collimators and/or diaphragms can serve as additional aids. In contrast to the customary operating reticle, the specific cleaning reticle is optimized toward attaining the desired illumination with regard to spatial and spectral properties generally in the projection system at the location to be examined. For this purpose, the reticle can also be combined with suitable diaphragms. During a scan of the cleaning reticle, e.g. the entire surface of the location to be examined is scanned using a small illumination spot analogously to a Braun tube. At the location of the illumination spot, therefore, detection and also cleaning and also repair can be effected in a spatially resolved manner.

The size, the position and/or the wavelength or bandwidth of the illumination spot can also be altered with the aid of suitable collimators and diaphragms by means of suitable setting. A collimator is appropriate in particular for monitoring measurements in the illumination system for beam shaping. A diaphragm can be used both in the

illumination system and in the projection system. Collimators and diaphragms can also be used together. Particularly in combination with the at least one tunable monochromator, which advantageously has a mechanism for continuously variable setting, the position and the size, the bandwidth and the wavelength of the used radiation can be set in a continuously variable manner for the purpose of detection, cleaning and repair. The intensity of the used radiation can also be altered thereby.

A commercially available semiconductor detector is preferably used for detecting the photons for the reflectivity measurement. In order to detect the photoelectrons, the location to be examined has to be electrically conductively connected to an electron collecting apparatus via an ammeter. The electron collecting apparatus can be e.g. a grid, a metal ring or a metal cylinder. It is also possible to use the wall of the EUV lithography apparatus for this purpose, particularly if intermediate walls are put in for separating different functional units, such as e.g. the projection system or the illumination system.

The presence of intermediate walls can also be used to set adapted residual gas atmospheres depending on the conditions prevailing in the respective partition. It is even possible to go as far as closing each individual optical element in an individual compartment. The individual mirror compartments are separated in the beam path by optical film filters, for example. In addition, the interior of the mirror compartment is connected to the surroundings via valves. In this case, the surroundings can be either the atmosphere in other mirror compartments, the atmosphere within the EUV lithography apparatus or else a direct gas supply from outside. What can even be achieved through skilful arrangement of valves, gas feed lines, gas discharge lines and the like is that pressure differences within a surface of a reflective optical element are achieved. This is highly advantageous particularly in the cleaning and repair modes.

The production method for reflective optical elements for an EUV lithography appliance is illustrated by way of example in Figure 1a. The starting point involves designing a coating design which theoretically fulfills specifications for use e.g. as a mask or as a mirror in the illumination optical unit or in the projection optical unit and can have a cover layer system and/or multilayer system that are/is variable in terms of the thickness distribution, inter alia, over the surface. The multilayer system and the cover layer system can be applied in a known manner, e.g. by electron beam evaporation or magnetron sputtering on a substrate. The finished coated reflective optical element is characterized by simultaneous measurement of the reflectivity and the photocurrent. In this case, measurement can be effected either angle- or energy-dispersively or with specific combinations of angles and energies.

Any desired EUV source can be used as radiation source, e.g. on the basis of relativistic electrons and laser- or discharge-induced plasmas. Particularly precise measurements can be obtained with well-collimated beams that lead to small, intensive illumination spots, such as are obtained with synchrotron radiation, for example. The entire coated surface is scanned with the aid of the illumination spot, such that two-dimensional thickness distributions are measured and geometrical coating parameters can also be determined precisely thereby and thus be altered in a targeted manner.

The measured curves are evaluated e.g. by considering the profile of the photoelectron current curve in the range of the reflectivity maximum, that is to say in the range of -3% to 1% around the wavelength or the corresponding angle. As an alternative, the measured photoelectron current curves are fitted to data modeled for different layer thicknesses. In this way, the layer thicknesses are obtained in an accurate manner

into the subangstrom range. In the corresponding model calculations it should be taken into account that the material- and layer-dependent exit depth of electrons and similar effects can influence the profile of the photoelectron current curves.

The thicknesses determined are compared with the desired coating design. In the case of deviations, the available coating parameters such as, inter alia, e.g. pressures, angles, flows, coating masks, movement patterns and many more can be correspondingly adapted and a new coating process can be carried out. The new reflective optical element is likewise checked with regard to its layers and/or layer thicknesses in the manner just described. If the measured thicknesses correspond to the design, the design itself can also be optimized by testing the reflective optical element in the radiation operation mode and/or in the simulation of an optical system with regard to fulfillment or non-fulfillment of certain specifications. If appropriate, the coating design is revised and a new coating process is carried out, which is checked in the manner explained. If both design and coating process are optimized, the series production of the desired reflective optical element can begin on the basis of the optimum coating parameters then known.

Any desired thickness distributions can be produced according to the method described above. One preferred embodiment involves producing a reflective optical element on the basis of an already tried and tested multilayer system, the coating process of which is already controlled well. The reflective optical element additionally comprises a cover layer system having a thickness distribution that is constant over the surface (see Figure 1b). Determining the thicknesses involves concentrating on the thicknesses of the cover layers. In a variation with respect to the method illustrated in Figure 1a, here the multilayer system is not tested in the actual radiation operation mode, rather simulation calculations of an optical system in which the multilayer

system with cover layer system is used are carried out. The results are compared with specifications established beforehand in order to decide whether or not the layer design has to be adapted further. In one modification of this method illustrated in Figure 1b, even further optimization loops could be provided, in which the multilayer system is tested individually or as part of said optical system in the actual radiation operation mode.

Figures 2a, b, c illustrate by way of example the energy-dispersively measured photocurrent curves and the in part correspondingly modeled curves for carbon thicknesses of 2 Å, 2.5 Å, 3 Å, 3.5 Å (Figure 2a), 3 Å, 6 Å, 12 Å (Figure 2b), 10 Å, 20 Å, 30 Å (Figure 2c) and in each case wholly without an additional carbon layer, in arbitrary units. The reflectivity curves for the samples with the thickest carbon layer in each case and for the sample without a carbon layer are also illustrated for comparison. Figures 2a, c illustrate the pure measurement curves. In Figure 2b the corresponding simulated curves are placed through the measured photoelectron current curve. All the photoelectron current curves are normalized identically, such that they are true to scale. In this case, it should be taken into consideration that the calculated and measured photoelectron current curves differ systematically by a constant background. This is owing to the fact that a photocurrent of greater than zero occurs at an exit depth of greater than zero even in the case of a field strength of zero in the vicinity of the free interface.

It is readily discernible, firstly, that the different carbon layers only minimally affect the reflectivity, but the changes in the photoelectron curve are very distinct. Secondly, it is readily discernible that, owing to this great alteration in the photoelectron current curve, the thickness can actually be determined in an accurate manner into the subangstrom range by fitting to modeled data.

In the case of the pure oxidation in accordance with Figure 2d, no displacement of the free interface is observed. At the same time, however, the photocurrent rises significantly on account of radiation absorption caused by the oxygen incorporated during the oxidation.

The relationship between the phase angle of a standing electromagnetic wave that forms in the case of resonance at the reflective optical element or the spectral profile of photoelectron current curve and the reflectivity is illustrated with reference to Figures 3a-n. Firstly, in the upper half, the calculated profiles of reflectivity and photoelectron current curves are illustrated and secondly, in the lower half of the figures, the spatial distribution of the intensity of the standing wave is illustrated once again by way of example for carbon layers having the thicknesses of 0 Å to 65 Å and in arbitrary units.

The position of the maximum reflectivity is very predominantly determined by the molybdenum-silicon multilayer system chosen by way of example. The position of the maximum reflectivity is also determined to a small proportion by overlying layers, here carbon for example. The presence of a cover layer system primarily affects the absolute value of the maximum reflectivity. The interface with respect to the vacuum, here specifically the interface of the carbon layer with respect to the vacuum, is designated as the free interface.

If the upper and lower halves of the figures are respectively compared, then, it is ascertained that, given a constant position of the intensity of the standing wave relative to the multilayer system, the position of the free interface changes with differing carbon thickness, such that the intensity of the standing wave at the free interface assumes different values for different carbon thicknesses. Low intensity values in the case of high carbon thicknesses are manifested in minimum photoelectron current in the case of resonance and high intensities in the case of low

carbon densities are manifested in maximum photoelectron current in the case of resonance. It is clearly discernible that here the profile of the photoelectron current curve in the range of the maximum reflectivity corresponds to the profile of the intensity of the standing wave in the region of the free interface.

A reflective optical element, as produced e.g. in accordance with Figure 1b, has, in principle, a construction as illustrated in Figure 4. Periodically repeating layer units j, j+1,n composed of four layers 21,22,23,24 in each case in this example are applied to a substrate 20. By way of example, alternating molybdenum layers 22 and silicon layers 21 with intermediate layers 23,24 as diffusion barrier are involved in this case. By virtue of the fact that the interfaces of the molybdenum and silicon layers 21,22 remain clearly defined by the diffusion barriers 23,24 even over a number of time periods, the maximum value of the reflectivity can be maintained for longer.

The topmost layer unit n is adjoined by the cover layer system 30, which in the present example has a thickness distribution that is constant over the surface. The cover layer system in this case consists of three layers 31,32,33, which can be e.g. silicon/molybdenum/silicon, molybdenum/silicon/silicon oxide or silicon/diffusion barrier/transition metal (both optionally with a topmost cover layer composed of carbon).

If, in particular, reflective optical elements comprising transition metals such as gold, platinum, rhodium, ruthenium, palladium, silver, rhenium, osmium, and/or iridium, in the cover layer system as in the last-mentioned example are involved, these are typically operated in a residual gas atmosphere comprising oxidizing and reducing gases or gas mixtures in order to avoid contamination and increase the lifetime. A residual gas atmosphere composed of hydrocarbon, water and oxygen is preferably involved in this case. In the case of the

hydrocarbon, in particular hydrocarbons comprising at least one oxygen atom, such as e.g. ketones and acids, have proved to be worthwhile. In particular, the use of methyl methacrylate (MMA) has proved to be worthwhile.

This applies not only to cover layer systems containing the chemical pure form of a transition metal, but also to cover layer systems comprising an alloy, compound or mixture containing a transition metal.

It has been found, however, that such a residual gas atmosphere also has a positive effect in the operation of reflective optical elements comprising a topmost cover layer composed of an oxide or carbon, e.g. a silicon/silicon oxide/carbon cover layer system, particularly if the reflective optical element is optimized to the effect that an intensity minimum of the standing wave is present in the case of resonance at the free interface.

Particularly effective suppression of contamination is achieved if the cover layer system comprising transition metal is designed in such a way that the maximum intensity of the standing electromagnetic wave that forms in the case of resonance is situated in the region of the free interface, in particular drawn back somewhat from the free interface (also see Figure 6a). Upon the start-up of such a reflective optical element, the residual gas atmosphere should firstly be set, by increasing the hydrocarbon partial pressure, such that a carbon layer grows. Measurements of the reflectivity and of the photoelectron current in the manner described above can be used to determine whether the maximum reflectivity and the maximum photoelectron current lie above one another. If not, then the individual partial pressures should be readjusted until an equilibrium is established at which the maximum reflectivity and the maximum photoelectron current lie above one another (also see Figure 6b). This method is illustrated in Figure 5. As

an alternative, it is also possible to choose an equilibrium point at which the two maxima are shifted slightly relative to one another.

If a reflective optical element in which, given the presence of a thin carbon layer, both maxima lie above one another is taken as a basis, then operation overall is a "carbon regime": upon the formation of the carbon layer immediately at the beginning of the irradiation, gaps in the transition metal layer are also filled with carbon, which prevents oxidation in addition to the carbon layer. If appropriate, the carbon layer that forms if the reflective optical element comes into contact with the normal atmosphere may already suffice. Excess carbon atoms are oxidized to form carbon dioxide and carbon gaps are simultaneously filled again. Continuous progression of these processes is ensured, in particular, by the photoelectrons that are made available in a maximum number at the free interface since the maximum of the intensity of the standing electromagnetic wave is situated at the free interface.

In order to implement the conditions just described in an EUV lithography apparatus, too, an EUV lithography apparatus such as is roughly depicted schematically in Figure 7 is suitable, for example. It has substantially three main constituents: the part 40 for providing a beam, the illumination system 50 for illuminating the reticle 60, and the projection system 70, which serves to image the structures of the reticle 60 on the wafer 80. In the present example, the illumination system 50 and the projection system 70 each have two mirrors 51, 52 and 71, 72, respectively. In this concrete example, all of the mirrors are reflective optical elements of the type described above, that is to say comprising a cover layer system whose layers have a constant thickness over the mirror surface.

In order to be able to operate the mirrors 51, 52 and 71, 72 with as little contamination as possible, both the illumination system 50 and the

projection system 70 have valves for setting the residual gas atmosphere, here e.g. valves 53, 73 for supplying hydrocarbon, valves 54, 74 for supplying water, valves 55, 75 for supplying oxygen, and also valves 56, 76 as outlet valves.

The part 40 of the EUV lithography apparatuses has, besides an EUV light source 41 and a collector 42, a grating 43 serving for monochromatizing the light. What is special about the grating 43 is that it can be mounted in a rotatable manner, such that the angle of incidence can be altered. This allows, firstly, between an operating wavelength for the exposure of the wafer 80 and a used wavelength for the detection of contamination, cleaning and/or repair of individual optical elements of the EUV lithography apparatus. Secondly, it also allows angular scans to be conducted in order to measure photocurrent and reflectivity measurements in a manner dependent on the angle of incidence or the wavelength at the reflective optical element 51. For this purpose, the reflective optical element 51 is connected to the grounded vacuum chamber 90 of the illumination system 50 via a cable 92 and an ammeter (not illustrated). In this case, the vacuum chamber 90 is used as an electron collector. Moreover, a photon detector 91 is provided, which can be pivoted into the beam path downstream of the reflective optical element for measurement purposes. The photon detector 91 is also connected to the grounded vacuum chamber wall 90 via a cable 93 and an ammeter and/or voltmeter (not illustrated). The lines that forward the measurement signals to a computer for data collection and evaluation are not illustrated. It goes without saying that other reflective optical elements or a plurality of reflective optical elements can also be measured in situ with regard to photoelectron current and reflectivity if the corresponding detectors are provided.

Preferably, ammeters in which a specific basic voltage can also be set are used. It is likewise possible to use voltmeters on which flowing currents can also be read.

The EUV lithography appliance shown in Figure 7 can either be operated in the operation mode, in which the mask 60 is illuminated and the structure thereof is imaged on the wafer 80. However, it can also be changed over to the detection mode, in which one or more reflective optical elements are checked for contamination. In the present example, the reflective optical element 51 is intended to be checked since this is exposed to the highest radiation loading. For this purpose, if appropriate, firstly the total pressure within the illumination system 50 is minimized. The surface of the reflective optical element 51 is irradiated and the photoelectron current and the reflectivity are measured in a manner dependent on the wavelength. The interplay of monochromator 43, collimator 42 and diaphragm 44 makes it possible to measure different locations on the surface of the refractive optical element 51 independently of one another. The contamination state of the reflective optical element 51 is determined from the determination of the spectral profiles of photoelectron current and reflectivity and/or comparison of the measured photoelectron current data with data modulated for different contamination states.

For the measurement, in particular of reflective optical elements 71, 72 from the projection system 70, for illumination purposes recourse is also had to the cleaning reticle, if appropriate in combination with a suitable diaphragm.

Depending on whether or not specific controlled variables are exceeded in the case of the contamination state, the system switches either to the operation mode, to the cleaning mode or the repair mode. Two controlled variables or two sets of controlled variables are used for this

purpose. The situation of the first controlled variable being exceeded means that the reflective optical element is contaminated to such a great extent that cleaning has to be carried out. The situation of the second controlled variable being exceeded means that cleaning does not suffice, rather the reflective optical element has to be repaired at the surface.

In the case where the system switches to the cleaning mode, depending on the contamination ascertained the partial pressures of the reducing and oxidizing gas fractions e.g. of hydrocarbon, water and oxygen are thoroughly modified, such that, upon irradiation with the used radiation, the contamination at the reflective optical element is reduced. If the contamination is removed to a sufficient extent, the system switches to the operation mode again.

For the case where it is necessary to switch to the repair mode, not only is the residual gas atmosphere adapted, but the incident beam is also modified in terms of its cross section and its position to the effect that material can be locally added and/or removed in a defined manner. For this purpose, use is made again of the rotatability of the grating 43 and also the collimator 42 and the slit diaphragm 44 and, in the case of cleaning or repair in the projection system 70, the cleaning reticle. As soon as the repair has been carried out, it is possible to switch to the operation mode again. This method sequence is also illustrated in Figure 8.

When carrying out the detection, cleaning and/or repair within the projection system it is possible to have recourse, in particular, to a cleaning reticle (not illustrated) in addition to the rotatable grating 43, the collimator 42, said cleaning reticle replacing the normal reticle 60 in the detection, cleaning and/or repair mode. The structures on the cleaning reticle are optimized toward illuminating the optical elements in

a targeted manner with spectrally modified radiation, if appropriate, for detection, cleaning and repair purposes. For this purpose, the cleaning reticle can also be mounted in a rotatable and translatable manner.

The changeover between detection/cleaning and repair mode and operation mode can be accompanied, in particular by the following measures: altering the residual gas composition, altering electric fields applied, if appropriate, in the region of the trajectories of the emitted photoelectrons (e.g. by means of a ring, a grid or a cylinder or putting the reflective optical element at a potential) for directing the electrons and shielding against positive ions and/or altering the beam characteristic. The beam characteristic is altered, inter alia, by setting the center wavelength, the bandwidth, the divergence and the intensity at the monochromator and/or cleaning reticle, by setting the beam diameter, beam angle and the divergence at the collimator, by setting the size of the beam spot and the wavelength by shading or selection of a reflection order by means of a diaphragm.

The electron collecting apparatus used can also be, besides the vacuum chamber wall 90, a grid, a wire ring or a cylinder, which are in each case electrically conductively connected to the reflective optical element to be measured or ground via ammeters. In particular, the reflective optical element to be measured can be electrically conductively connected to an ammeter via a cable. In this case, too, it is possible to use a meter in which the voltage can also be set.

In order to generate a defined electromagnetic field between the reflective optical element to be measured and the electron collecting apparatus, a defined electrical potential is applied with the aid of an additional component, such as e.g. a ring, a cylinder or a grid. In this case, this component can be configured with any desired complexity and is connected to a voltage source. In order to generate a defined

electromagnetic field, by way of example it is also possible for the reflective optical element to be measured itself to be put at a specific voltage.

Although the invention has been discussed in conjunction with preferred exemplary embodiments, it is not restricted thereto.